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RESEARCH MEMORANDUM

RECENT INFORMATION ON FLAP AND TIP CONTROLS

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Langley Aeronautical Laboratory
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INTRODUCTION

In the past few years, research programs on controls have been expanded to include systematic transonic and supersonic investigations of new types of control devices and to adapt the controls developed through subsonic research to the supersonic regime. The results now available are sufficiently extensive to warrant an evaluation of the progress to date and to establish certain trends. The data presented in the present paper are used to outline these trends rather than to give a completely comprehensive summary of the available data. A bibliography of references, however, is included.

SYMBOLS

M	stream Mach number
q	stream dynamic pressure
p	stream static pressure
p_l	local surface pressure
P	pressure coefficient, $\frac{p_l - p}{q}$
x	chordwise distance from wing-section leading edge
c	wing chord
c_T	total control chord
c_f	control chord behind hinge line
$\bar{c}$	wing mean aerodynamic chord

$\bar{c}_c$ control mean aerodynamic chord

b/2 wing semispan

S semispan-wing area

S_T total control area

S_b control area ahead of hinge line

Q moment of control area behind hinge line about hinge line

α wing angle of attack

δ control deflection relative to wing

L semispan-wing lift

L' semispan-wing rolling moment

M' semispan-wing pitching moment about 50-percent station of wing mean aerodynamic chord

H control hinge moment about hinge line

C_L lift coefficient, L/qS

C_l rolling-moment coefficient, $L'/q2Sb$

C_m pitching-moment coefficient, $M'/qS\bar{c}$

C_h control hinge-moment coefficient, defined as $H/q2Q$ for flap controls and $H/qS_T\bar{c}_c$ for tip controls

Slope parameters:

$$C_{L_\delta} = \frac{\partial C_L}{\partial \delta}$$

$$C_{l_\delta} = \frac{\partial C_l}{\partial \delta}$$

$$C_{m_\delta} = \frac{\partial C_m}{\partial \delta}$$

$$C_{h_\delta} = \frac{\partial C_h}{\partial \delta}$$

$$C_{h_\alpha} = \frac{\partial C_h}{\partial \alpha}$$

All slopes were obtained at $\alpha = 0^\circ$ and $\delta = 0^\circ$.

DISCUSSION

The fundamental requirement of a control, at any speed, is that it produce the necessary lift, pitching moment, or rolling moment to control the aircraft in flight. Considerable testing of controls at high speeds has shown that the desired effectiveness can usually be obtained without difficulty. Since the supersonic theory for predicting control effectiveness is cumbersome and the assumptions are often not well-supported by experiment, simpler methods of estimating the control effectiveness are desired. It is to be expected that, to a first order, the lift of a control is directly related to the area of the control, and the moment of the control forces about a given axis is directly related to the moment of the control area about that axis. This simple concept is substantiated by data presented in figures 1 and 2 which show the results of tests in the Langley 4- by 4-foot supersonic pressure tunnel at Mach number 1.61 of a delta wing and of a trapezoidal wing. In these figures, the slopes of the curves of lift, rolling-moment, and pitching-moment coefficients with control deflection are plotted as functions of the control area, control-area moment about the roll center, and control-area moment about the pitch center, respectively, for the control configurations tested. It is evident that to a first order it is possible to estimate from these correlations the effectiveness of any control on the wings shown, regardless of control plan form. Similar results have been obtained for wings of other plan forms (refs. 1 to 3). Some flight results (ref. 4) indicate that correlations may not be obtainable for some controls on high-aspect-ratio, highly swept wings.

In view of the fact that satisfactory control effectiveness can be obtained and usually can be estimated, a primary objective of research on controls at the present time is to develop methods for balancing the forces acting on the controls to improve the hinge-moment characteristics. In order to reduce the magnitude of the control hinge moments, several methods have been used, such as overhang nose balances, horn balances, tip controls, all-movable wings, tabs, and paddle balances. Until recently, very few data have been available on overhang balances at high speeds; however, recent transonic and supersonic tests of trailing-edge controls having various amounts of overhang nose balance have been made on the transonic bump in the Langley high-speed 7- by 10-foot tunnel and in the Langley 9- by 12-inch supersonic blowdown tunnel. Figure 3 shows the variation with Mach number of the hinge-moment-parameter slopes with control deflection and with angle of attack for the two extreme test configurations, one having no overhang balance and the other having 100-percent balance. Data for the configurations having a balance area between 0 and 100 percent fall between the curves shown. Throughout this paper, percent balance is defined as the ratio of control area ahead of the hinge line to control area behind the hinge line, expressed as a percentage. For this type of control, the hinge-moment-coefficient slopes, which are based on the moment of the control area behind the hinge line, have been converted to hinge-moment-parameter slopes, which are based on the moment of the total control area about the control leading edge, in order to make the data for the two controls directly comparable. It should be noted that all the tests were made with a rounded leading edge on the control and that the 9- by 12-inch-tunnel data were obtained on a wing mounted on a half-body, which may explain some of the discrepancies in the data from the two tests. In general, the data indicate that the nose balance is effective in changing the hinge moment due to control deflection throughout the speed range tested. The nose balance causes a much larger change in hinge moment due to wing angle of attack at supersonic speeds than at subsonic speeds. Since these slopes were obtained at a control deflection of 0° and an angle of attack of 0°, it appears that, in order to gain more insight into the effectiveness of the nose balance at subsonic and supersonic speeds, it will be necessary to consider the effect of control deflection and angle of attack.

Figure 4 shows for a Mach number of 0.60 and a Mach number of 1.96 the variation of the hinge-moment parameter with control deflection at an angle of attack of 0° and with angle of attack at a control deflection of 0° for the two control configurations discussed in the previous figure. In both the subsonic and supersonic cases, the unbalanced control, as designated by the solid curves, has fairly linear characteristics and for the Mach numbers shown there is only a small change in slope due to Mach number of the hinge-moment curve with control deflection near $\delta = 0^{\circ}$. For the 100-percent-balanced control, the subsonic curve shows a large balancing effect with increasing control deflection at the small deflections. At supersonic speed, the 100-percent-balanced control shows less balancing action than it did at subsonic speed. Other data at angles of attack have shown that at supersonic speeds the balance is ineffective at positive control deflections when the nose of the control lies in the dead-air region behind the wing but has a strong balancing effect at negative control deflections when the control nose is exposed. At all the test angles of attack, the effect of the nose balance is less at subsonic than at supersonic speed when the control deflection is 0°.

Since at supersonic speeds the dead-air region from the wing seems to be important, it would appear that changes in wing section to minimize this region would improve the balancing effectiveness of this type of control. The results of two-dimensional tests in the Langley 9-inch supersonic tunnel at a Mach number of 2.40, in which changes in section were made, are shown in figure 5. The hinge-moment-parameter slopes, which were taken from fairly linear curves, are plotted as functions of the ratio of control balancing area to total control area. Models were tested for two of the sections with different balance-area ratios as shown by the curves. Models of all four sections for a balance-area ratio of 0.375 were tested. For these tests an area ratio of approximately 0.6 would be required to balance the hinge moment due to control deflection for the basic configuration (denoted by the solid curve); whereas a ratio of 0.4 is all that is required to balance the hinge moment due to angle of attack. The changes in section had only a minor effect on the hinge moment due to control deflection, contrary to what might have been expected, and had considerable effect on the hinge moment due to angle of attack.

In figure 6, pressure distributions are presented for a typical section modification, in this case wing bevel, to illustrate this phenomenon in more detail. The solid curves indicate the pressure variation along the chord on the upper surface and the dashed curves show the pressure variation on the lower surface. The left-hand side of the figure shows the effect of a change in section on the pressure distributions due to a large control deflection at an angle of attack of 2°. In this case, beveling the wing ahead of the control increased the load on the balancing portion of the control, but it also increased the load on the control behind the hinge line so that the net effect on the hinge moment was negligible.

The right-hand side of the figure shows the effect of a change in section on the pressure distribution due to an angle of attack of 8° with a control deflection of 0°. In this case, there is little change on the upper surface; however, the lower-surface peak-pressure point moves forward and increases in intensity. Behind the hinge line there is some forward shift in the center of pressure of the load. The resultant hinge moment is therefore much more positive because of the modification of the wing section. Another way of increasing the balancing action of the overhang-nose-balance control is to increase the gap between the wing and the control so that the control behaves more like an isolated wing. However, such a modification results in a drag penalty, as do the modifications to the wing section.

A second method for reducing the hinge moments obtained on trailing-edge controls at supersonic speeds is to add a horn balance, ahead of the hinge line, to the outboard portion of the control. Figure 7 shows a correlation of hinge-moment-slope parameters at $M = 1.60$ obtained from recent tests of horn-balanced controls in the Ames 6- by 6-foot supersonic tunnel (ref. 5), tests in the C.I.T. Jet Propulsion Laboratory 12-inch supersonic tunnel (refs. 6, 9, and 16), and on a Langley Pilotless Aircraft Research Division rocket research model (refs. 17 and 18). The correlation with the ratio of control-balance area to total control area is approximately linear, even though both triangular horns and rectangular horns are included on delta wings having leading-edge sweeps from 60° to 75°. As compared to the overhang nose balance, the balancing horns are considerably more effective in reducing the hinge moments due to control deflection and angle of attack. A horn of only one-third the control area balances C_{h_δ} and a horn of only 15 percent of the control area balances C_{h_α} for this Mach number condition. With this type of control, it is of course impossible to balance both C_{h_δ} and C_{h_α} closely with one balance configuration.

Still another method of reducing the control hinge moments at supersonic speeds is to use tip controls, in which the hinge-line location may be chosen to balance the forces acting on the control. Figure 8 presents recent data on 60° half-delta tip controls on a 60° delta wing from Langley Pilotless Aircraft Research Division rocket tests (ref. 28) and tests in the Langley 9- by 12-inch supersonic blowdown tunnel (refs. 29 and 30), the Langley 4- by 4-foot supersonic pressure tunnel (ref. 13), the Langley 9- by 9-inch Mach number 4 blowdown jet, and the Langley 11-inch hypersonic tunnel. These data extend the speed range for which tip-control data were previously available to the hypersonic region and increase the range of balances tested. For comparative purposes, experimental curves are also shown for the hinge-moment-slope parameters of a 30-percent-chord trailing-edge control obtained from two-dimensional tests in some of the same test facilities (refs. 20 to 22). In general, the hinge-moment-slope parameters for the tip controls vary with shifts in the hinge-line location in a systematic manner, as would be expected. The linear-theory curve is shown for the 55-percent-balance condition, which corresponds to the square test points of the experimental data.

In view of the interest shown in data at the highest available Mach number, figure 9 shows in more detail the hinge-moment characteristics with control deflection and angle of attack for the two types of controls tested at a Mach number of 6.90. The hinge-moment-coefficient scales are different for the two controls and the characteristics are not directly comparable because of the differences in moment areas on which the coefficients are based. The linear-theory curves are shown for the range of test angles, although the linear theory is obviously invalid at this Mach number except for very small angles and extremely thin wings.

The shock-expansion theory gives a reasonable prediction of the hinge-moment-coefficient variation with control deflection for the trailing-edge control and gives excellent prediction of the variation of hinge-moment coefficient with angle of attack. For the tip control, the shock-expansion theory, computed by assuming that the flow over the control was completely two-dimensional, provided an excellent prediction of the hinge-moment characteristics at the small angles. The linear-theory agreement with the shock-expansion theory at the small angles is fortuitous as a result of the section of the particular control tested.

The agreement between shock-expansion theory and experiment for the control hinge-moment coefficient due to control deflection, shown in this figure, tends to give an overly optimistic impression of our ability to predict the flow characteristics at this Mach number. Figure 10 shows the experimental and shock-expansion pressure distributions for the trailing-edge control, first with a control deflection of 16° and an angle of attack of 0° and second with an angle of attack of 16° and a control deflection of 0°. The prediction of the angle-of-attack effect is very good; however, the prediction of the control-deflection effect is poor. On the wing lower surface, the flow separates ahead of the hinge line and then gradually increases in pressure to the trailing edge. The effects on the hinge moment of the discrepancies between experimental and theoretical pressure distributions are of a compensating nature and therefore the experimental loss in hinge moment is considerably less than the experimental loss in lift. A similar investigation of the flow details for the tip-control case is needed to understand better the validity of the theoretical predictions at this Mach number.

To study more closely the effect of changes in tip-control hinge-line location and plan form at lower Mach numbers, extensive tests have been made in the Langley 4- by 4-foot supersonic pressure tunnel (ref. 13) and in the Langley 9- by 12-inch supersonic blowdown tunnel (refs. 29 and 30 and unpublished data). The correlation of the hinge-moment-slope parameters with area ratio at a Mach number of 1.6 for the 10 configurations tested is presented in figure 11. From this figure it is evident that the slope parameters correlate satisfactorily with area ratio, despite the secondary effects of plan form, which cause some scatter of the points. The tip controls may be balanced at this condition for an area ratio near 0.4, and the ratio for balancing C_{h_δ} is very close to the ratio necessary to balance C_{h_α}.

The balancing of control hinge moments at a control deflection of 0° and an angle of attack of 0° is likely, however, to prove misleading in view of the effect of angle of attack and control deflection. The most closely balanced controls tend to have the most nonlinear hinge-moment characteristics. Figure 12 shows the hinge-moment-coefficient curves with control deflection at several angles of attack for a 55-percent-balanced control at a Mach number of 1.61. As the angle of attack is increased to 12°, the curves become increasingly nonlinear and in some regions the control is overbalanced. On the right-hand side of the figure, the hinge-moment curves for a control having less balance show an increased slope but no regions of overbalance with control deflection. In an attempt to reduce the nonlinearities, a fence was installed at the wing-control parting line to prevent crossflow through the angular gap due to deflection of the control (ref. 34). When this fence was installed, the average effect was an improvement in the linearity of the curves. A similar linearizing effect of the fence was also found in tip- and horn-balanced-control tests in the Langley 9- by 12-inch supersonic blowdown tunnel (refs. 30 and 14).

Other balancing devices which have been tested, but which are not discussed in detail here, are the paddle balances, tabs, and all-movable controls. The paddle balances (ref. 5) are very effective at supersonic speeds in reducing C_{h_δ} and can be used alone to reduce C_{h_α}; however, there is a very large drag penalty associated with their use. Tabs (refs. 33 and 34) are less effective at supersonic speeds than at subsonic speeds in balancing the hinge moments and require large deflections. All-movable delta controls appear encouraging at supersonic speeds because there is very little shift of the center of pressure with body angle of attack or wing deflection; however, there is a large shift in center of pressure through the transonic speed range and the method of mounting poses considerable problems.

CONCLUSIONS

Correlations have been obtained, on the basis of simple geometric parameters, which permit quick estimates of the effectiveness and hinge-moment characteristics of controls of any plan form or location on wings of many plan forms at supersonic speeds. Closely balanced controls tend to exhibit nonlinear hinge-moment characteristics with control deflection and angle of attack. On tip and horn-balanced controls, a fence installed at the wing-control parting line produces a linearizing effect.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 1, 1953.

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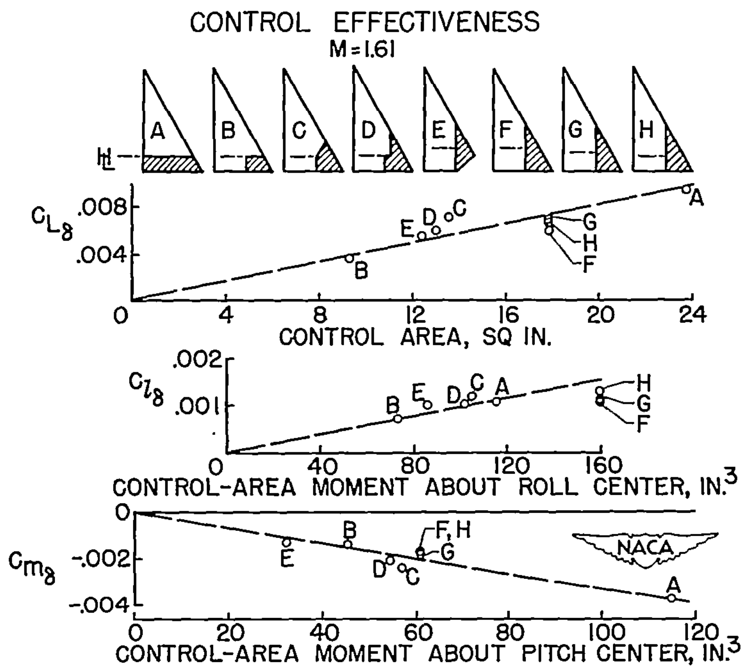

Figure 1

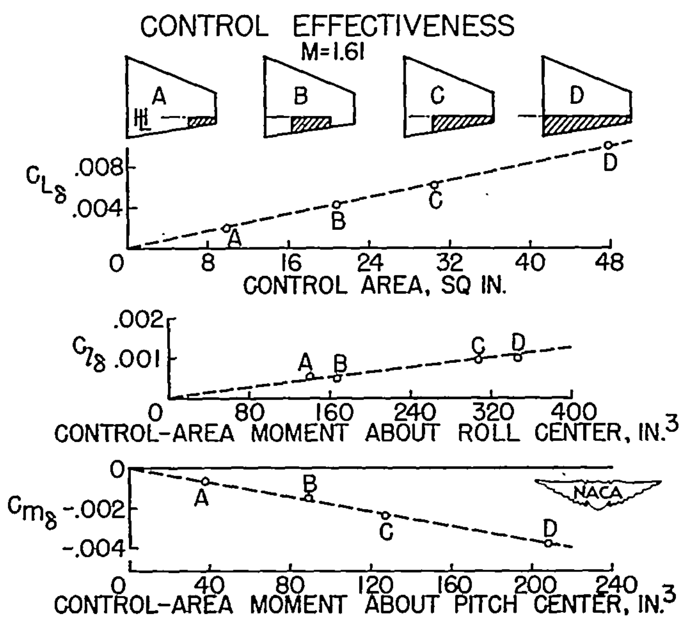

Figure 2

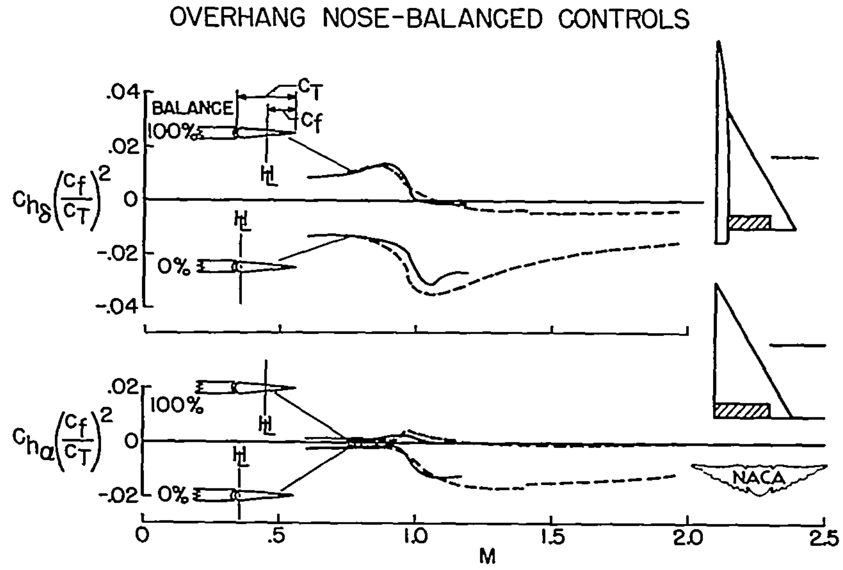

Figure 3

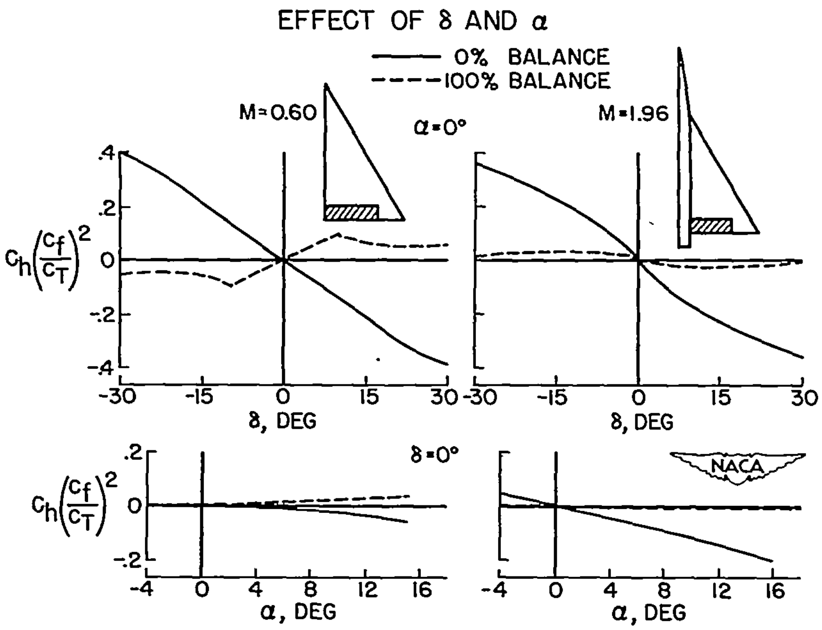

Figure 4

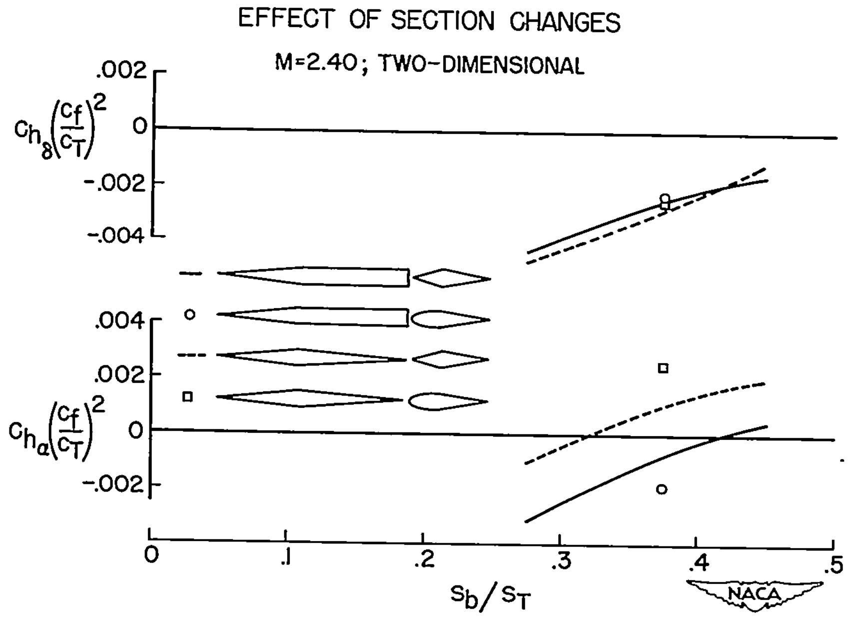

Figure 5

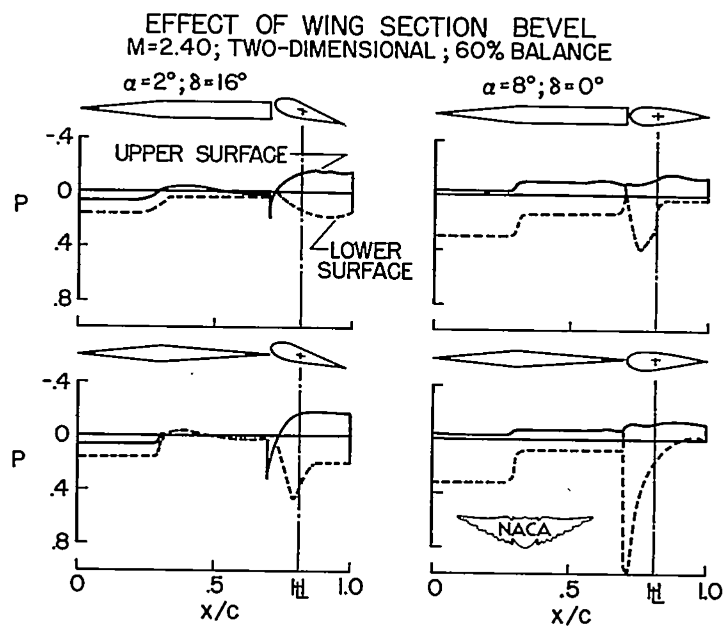

Figure 6

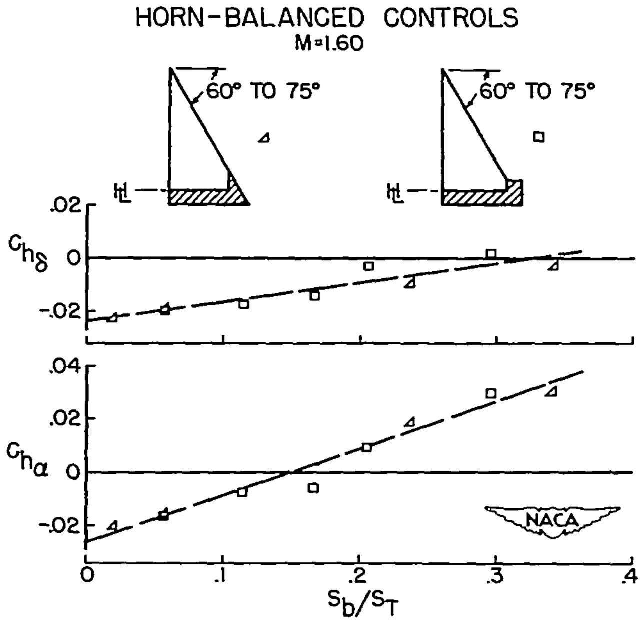

Figure 7

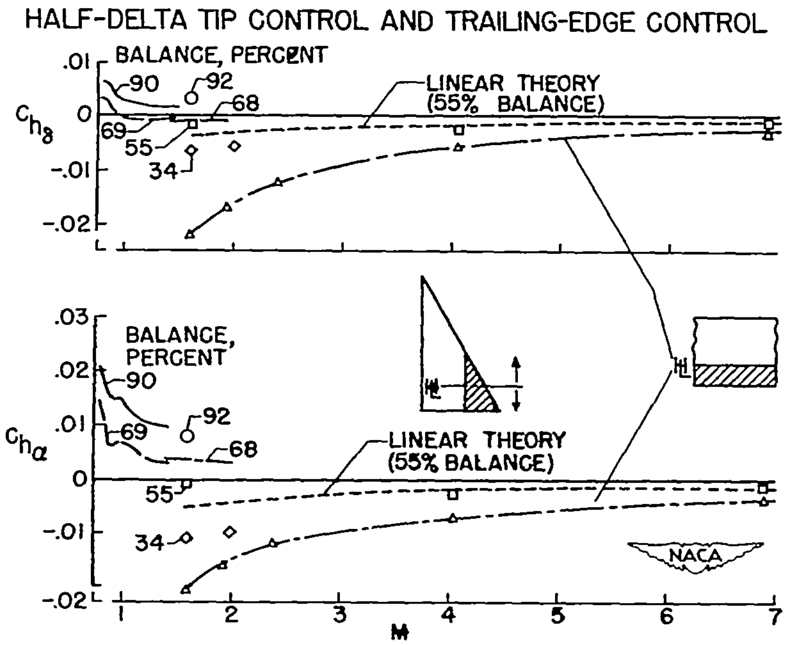

Figure 8

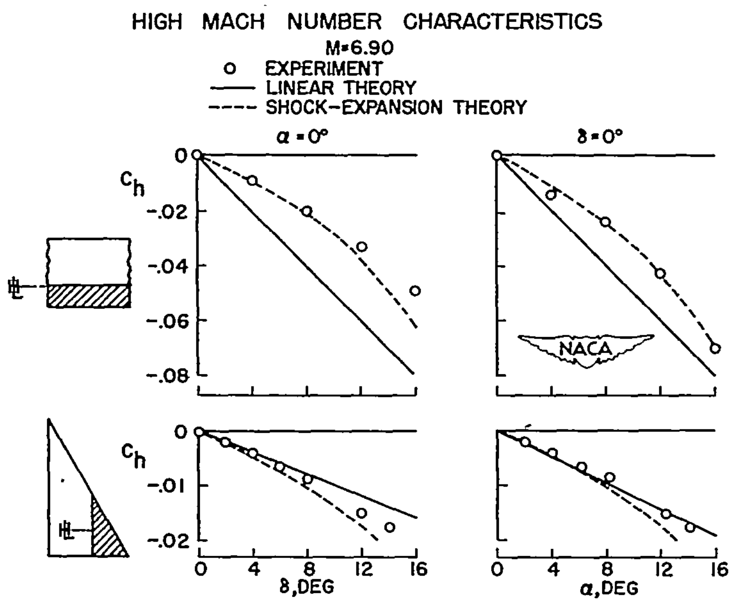

Figure 9

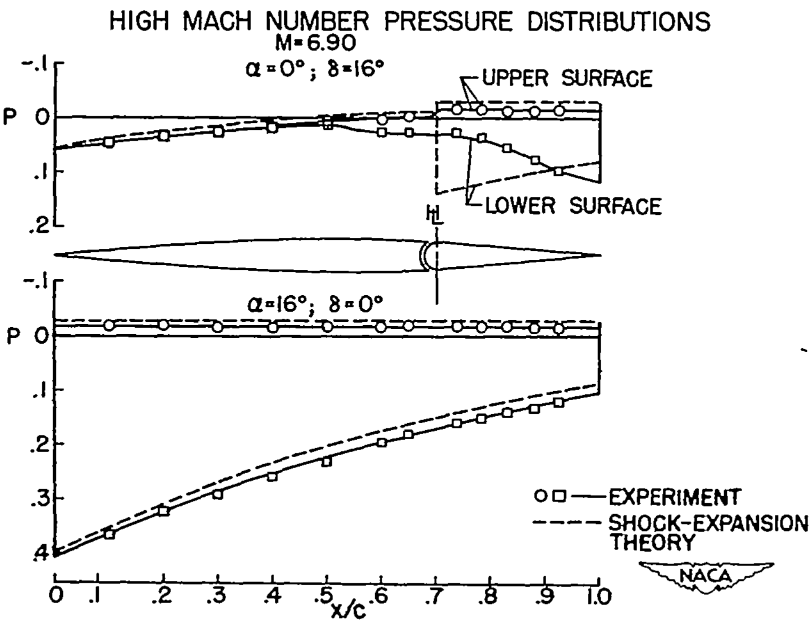

Figure 10

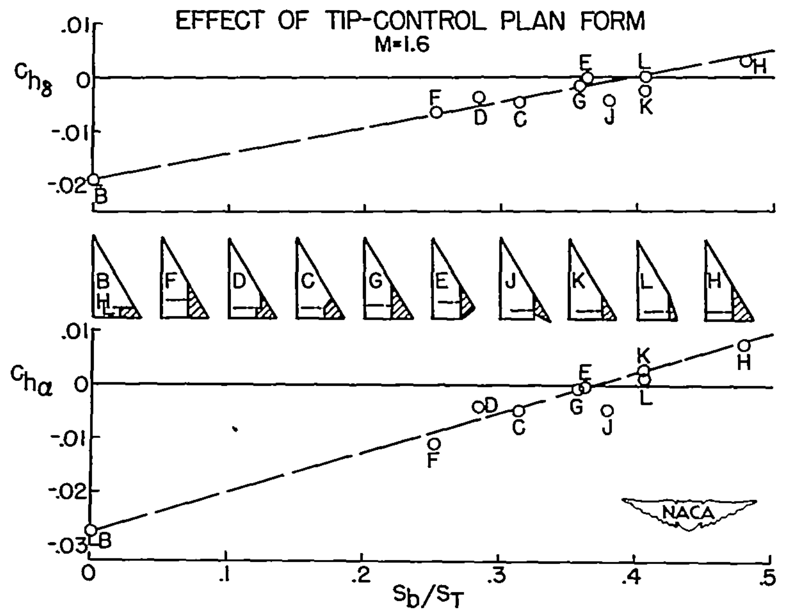

Figure 11

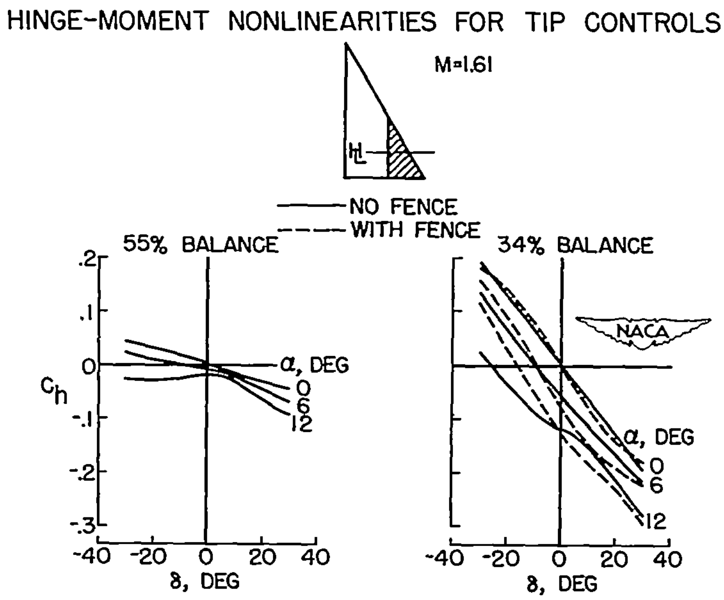

Figure 12

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